DØ Note 3254

Frequency Characteristics of Filtering Capacitors for Run 2 Calorimeter Preamplifier Motherboards

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1 Introduction

Filtering capacitors are typically used on the power supply lines of electronic circuits to smooth out any ripples and spikes on the supply voltages. We present measurements of the frequency response of various capacitors used for filtering on the Run 2 calorimeter preamplifier motherboards.

2 Measurement Technique

We use the Hewlett-Packard 3577A Network Analyser to make the following measurements. This device is used to generate a logarithmic frequency sweep and the transfer function of an RC circuit using the capacitor (or capacitors) in question is measured. Figure 1 illustrates the procedure. By normalizing input B to input A the transfer function of the RC test circuit is measured. Knowing R_{test}, the characteristics of C_{test} can be deduced.

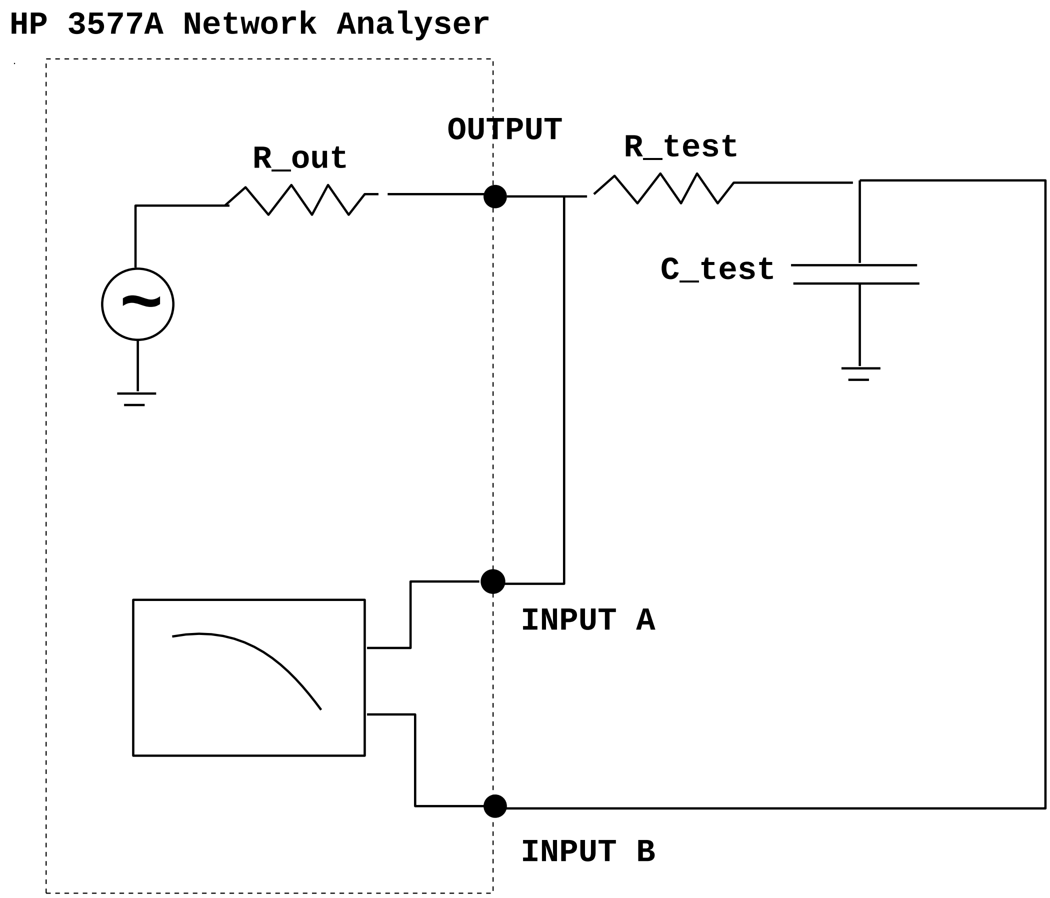

Figure 1: Illustration of the method used to measure the frequency characteristics of a capacitor.

3 Results

We perform the measurements on four capacitors: Sprague 150 μF electrolytic, 4.7 μF ceramic, 2.2 μF ceramic, and 0.1 μF ceramic. In reality capacitors have some stray inductance and resistance in series with the capacitance. A capacitor can thus be modelled as shown in figure 2. Plot 1 shows the magnitude of the transfer function vs frequency of the RC circuit with the 150 μF electrolytic capacitor and $R_{test} = 6.6\ \Omega$ on a log-log plot. The measurement shows that for frequencies larger than 2 kHz, the resistive component dominates the impedance of the capacitor. Beyond 60 kHz, the inductive component causes the impedance of the device to increase with frequency and we lose the filtering capability. We model the 150 μF capacitor with $L_s = 0.7\ \mu$H and $r_s = 0.7\ \Omega$. Plot 2 shows that we can reproduce the measurement of plot 1 with a calculation based on this model.

In order to provide filtering capability at high frequency, we need capacitors with smaller series inductance and resistance. Plot 3 shows the measurement of the 0.1 μF capacitor and $R_{test} = 10$ kΩ. Upto 2 MHz we see the characteristic $(\text{frequency})^{-1}$ dependence of the capacitor's impedance. To increase the measurement sensitivity at higher frequencies we repeat the measurement with $R_{test} = 50\ \Omega$, shown in plot 4. We note the effect of a small series inductance producing an LC notch at a frequency of approximately 7 MHz. Plot 5 shows the calculated transfer function of the same circuit, modelling the capacitor with $L_s = 5$ nH and $r_s = \emptyset\ \ \Omega$.

Plots 6 and 7 show the transfer function measured with $R_{test} = 10\ \Omega$ and the 150 μF and 0.1 μF capacitors connected in parallel. The purpose is to attain adequate suppression of the transfer function over a wide range of frequencies. We note the peak at 550-600 kHz where neither capacitor is providing adequate filtering. In plot 6 the test circuit components are mounted on a piece of cardboard, while in plot 7 they are mounted on a printed circuit test board to check how sensitive the measurements are to the differences in stray capacitances and inductances. We find the differences to be small. Plot 8 shows the calculated response with the model parameters given above, reproducing the measurement.

In order to provide filtering in the 600 kHz frequency region, we try 2.2 μF and 4.7 μF ceramic capacitors. Plot 9 shows the transfer function of the 2.2 μF capacitor with $R_{test} = 50\ \Omega$. The LC notch due to the series inductance is at approximately 1.4 MHz. Plots 10 and 11 show the measured

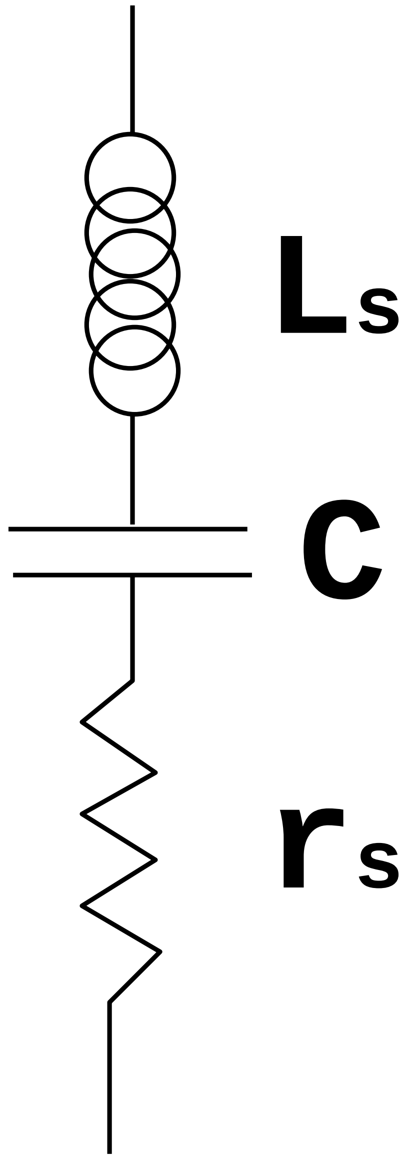

Figure 2: A physical capacitor modelled as a perfect capacitor with series inductance and resistance.

transfer function of the 0.1 μF, 2.2 μF and 150 μF capacitors in parallel, with R_{test} = 10 Ω (with the components mounted on a test board and on a cardboard substrate respectively, giving similar results). The peak in the transfer function at 600 kHz is suppressed by the 2.2 μF capacitor.

Plot 12 shows the transfer function of the 4.7 μF capacitor with R_{test} = 10 Ω. The LC notch due to the series inductance is at approximately 1.0 MHz. Plot 13 shows the calculated transfer function of the same circuit, modelling the capacitor with L_s = 4 nH and r_s = 5 mΩ. Plot 14 shows the measured transfer function of the 4.7 μF and 150 μF capacitors in parallel, with R_{test} = 10 Ω. The filtering at high frequency provided by the 4.7 μF capacitor is slightly better than that provided by the 2.2 μF capacitor. Plot 15 shows the corresponding simulated transfer function with the model parameters indicated above, reproducing the measurement.

4 Conclusions

We have measured the frequency response of the electrolytic 150 μF and the ceramic 0.1 μF, 2.2 μF and 4.7 μF capacitors, with the goal of providing adequate filtering of the power supply on the Run 2 calorimeter preamplifier motherboards. In general the capacitors can be modelled as a perfect capacitor with series inductance and resistance. From the measurements, we deduce that the series inductance and resistance of the electrolytic capacitor is 0.7 μH and 0.7 Ω respectively, while the same parameters for the ceramic capacitors are 4-5 nH and $\sim$ 5 mΩ respectively. We note that the parallel combination of the 150 μF and the 0.1 μF capacitors does not provide adequate filtering in an intermediate frequency range, a deficiency that can be corrected by the addition of a 2.2 μF or 4.7 μF capacitor in parallel. For the Run 2 calorimeter preamplifier motherboards, we recommend the use of the ceramic 0.1 μF and 4.7 μF capacitors and the electrolytic 150 μF capacitor all connected in parallel.